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Prediction of Electronic Failures

UTILIZING a relatively unexplored approach to the problem of higher reliability of electronic equipment, the National Bureau of Standards is investigating the feasibility of detecting incipient failures long before they perceptibly affect over-all performance. The study has as its goal quick and easy failure-prediction checks by unskilled personnel. It is being conducted under the sponsorship of the Office of Naval Research by J. H. Muncy of the NBS engineering electronics laboratory. In an NBS technique, experimentally evolved, a maintenance man simply plugs a portable failure-prediction unit into the slightly-modified equipment to be checked and turns a multipoint selector switch; a red light flashes on to identify stages or components that have deteriorated below safe levels and have become prospective causes of equipment failure. In accelerated-aging experiments on a military radio receiver, the Bureau has succeeded in predicting a majority of failures many hours before they occur.

As applications of radio and electronic equipment continue to increase in extent and importance, problems of maintenance and reliability become more and more serious. This is particularly true of military electronic equipment. In addition to depending on it extensively for military communications, the Armed Forces increasingly rely on electronic equipment for radar detection of aircraft and vessels, for the automatic aiming, firing, and detonating of weapons and missiles, and for numerous instrumentation and control applications. The inevitable complexity of much of this equipment augments the danger that failures of components will cause failures of essential equipment at critical times. Although much progress has been made toward better electronic dependability, particularly through improved-quality components, the reliability of present-day electronic equipment still leaves much to be desired. In some large and highly specialized electronic installations, such as the Whirlwind computer, valuable means for automatically detecting marginal stages have been built into the equipment. However, very little study seems to have been made of the practical possibility of detecting incipient failures by means of simple routine checks with portable test equipment.

The fact that large bombers may use some 2,000 vacuum tubes suggests the magnitude of the problem of attaining satisfactory reliability in military electronic equipment. It has been estimated that a typical home television receiver, with about 20 tubes, averages one tube failure for every 1,200 hours of operation; with the same rate of failure, a plane with 2,000 tubes would have one failure every 12 hours. Yet much more severe environmental conditions in the plane increase failure probabilities.

Either sudden or gradual failure of a tube or other component may cause failure of electronic equipment to function properly. Although improvement of quality seems to be the only way to reduce sudden failures of components, surveys have indicated that at least half of all equipment failures are produced by gradual failures of components. The NBS work has been concerned with practical means of spotting these gradual failures before the equipment becomes inoperative.

In multistage equipment it is impossible in general to detect such incipient failures by input-output performance measurements, because the tolerances of an

over-all measurement will usually mask the performance decrease of one stage that may precede and presage failure in that stage. Daily variations in measured gain of a typical piece of equipment are greater than the change caused by the gradual deterioration of one tube in one stage; as the tube continues to deteriorate, the time at which impairment of over-all performance becomes detectable may virtually coincide with the time at which over-all failure occurs. Successful failure prediction therefore requires that the condition of each important stage or small group of stages be established individually.

The designer of electronic equipment must allow certain design tolerances for the performance of any type of component, whether tube, resistor, capacitor, or complete subassembly. Component performance may vary both positively and negatively with time, and the designer must allow for these drifts as well as for initial spread. In equipment designed for reasonably long life, a component can gradually deteriorate a great deal before it reaches the level of minimum acceptable performance (the failure level). The gradual nature of this deterioration gives rise to the possibility of prediction of failures long in advance.

Tube failures constitute by far the most common cause of electronic equipment failure, and the experimental NBS failure-prediction system depends primarily on the sensing of decrease in tube transconductance of critical stages. This is done by operation of the tube as a resistance-coupled amplifier, with a 3,000-cycle signal applied, and the sensing of whether or not the voltage gain has fallen below a predetermined limit. This test also permits detection of changes in components other than the tube if the changes affect the gain of the stage. In addition, provision is made for voltage and current measurements and for checking capacitors for leakage, although in the equipment studied practically all the failures have been tube failures detectable by the voltage-gain check.

The military receiver selected for experimentation at the Bureau, an 18-stage guard-channel receiver, required only slight modification for adaptation to the failure-prediction system. The circuits were first examined for sensitivity to weak and gassy tubes. The sensitive stages comprised the r-f amplifier, first mixer, high i-f amplifier, second mixer, two stages of low i-f, two crystal oscillators, and two frequency multipliers. Insensitive stages were signal and avc detectors, audio and avc amplifiers, series and shunt noise limiters, and

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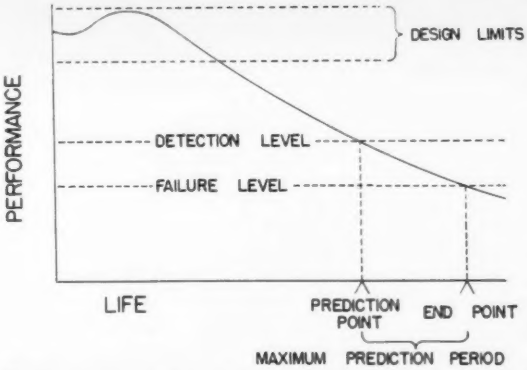
Contents

Making a failure-prediction test on a military radio receiver (left) at NBS. The connector from the experimental prediction-test unit (right) is simply plugged into the connector that has been added to the slightly modified receiver. It then takes only a few seconds to make an incipient-failure check by rotating one of the multipoint selector switches (large knobs); the alarm light (near left knob) flashes on if any of the stages of the receiver have deteriorated below a safe level. The test method relies principally on detection of decrease of tube transconductance, but provision is also made (small switches) for measurement of voltages and currents and for sensing of capacitor leakages.



Curve representative of change of performance level with service life of electronic component. Dependability of electronic equipment may be improved by quick semiautomatic checking routines to detect components that have deteriorated below safe level before they can cause failure.

avc gate. Modification of wiring was sufficient to permit checks on the 10 sensitive stages. Changes consisted chiefly in provision for breaking grid and plate return leads to permit insertion of an audio signal and measurement of gain. Necessary connections were made to a multi-point connector into which the plug from the failure-prediction unit could be inserted. Circuit changes entailed use of only about 7.5 percent additional components, mostly capacitors and r-f chokes; wiring and parts were all fitted without difficulty into available space in the receiver.

The experimental NBS prediction test unit includes a 3,000-cycle oscillator, voltage-sensing circuits, a leakage detection circuit, and an alarm light. As the main selector switch is rotated in a check of the gains of the various stages of the receiver, different predetermined levels of audio signal are applied to the grid of each stage. Each input signal is preadjusted so that, if the gain of the stage has changed by more than a safe amount, the voltage-sensing circuits will actuate the alarm light. After the test unit has been plugged into the receiver, the operator needs only a few seconds to rotate the selector switch and discover any weak stages. This switching could be speeded up and made automatic by use of stepping-type switches. A separate 3-position switch on the test unit permits capacitor-leakage sensing and voltage-and-current sensing in addition to the gain sensing. For field use the unit could be made compact and portable.

In laboratory evaluation of this failure-prediction system, 1,000-hour accelerated-aging tests were run at the Bureau on six of the modified receivers. To accelerate failures, temperatures of components were cycled between 10° C and 120° C with a 15-minute total period, voltages were maintained at 15 percent above design values, and switching transients were simulated by periodical raising of plate voltages to 150 percent of normal for one second. Since the emphasis was upon producing gradual failures, vibration and shock were not included. Prediction checks were made at five-hour intervals.

A total of 79 tube failures occurred in the six 11-tube receivers during the 1,000-hour test period. Sixty-five of these failures, or about 80 percent, were of a gradual and predictable nature—either low transconductance or gassiness—while the other 14 were caused by unpredictable open heaters (seven) or shorts (seven). The fact that other tube-failure analysis studies have shown only about 50 percent of failures to be gradual is probably largely attributable to the presence of vibration and shock. Six of the 14 opens and shorts at the Bureau occurred during one 60-hour period, during which heaters and plates were cycled one minute on and one minute off; the other eight were spread over 940 hours.

Fifty-eight of the 65 predictable tube failures were accurately predicted many hours before the receiver failed. Of the seven predictable failures not successfully predicted, two were in stages not being checked, four were in a single stage where parasitic oscillations interfered with measurement, and one was masked by the change in value of an overloaded resistor. Failures of components other than tubes were negligible and do not warrant any conclusions as to predictability.

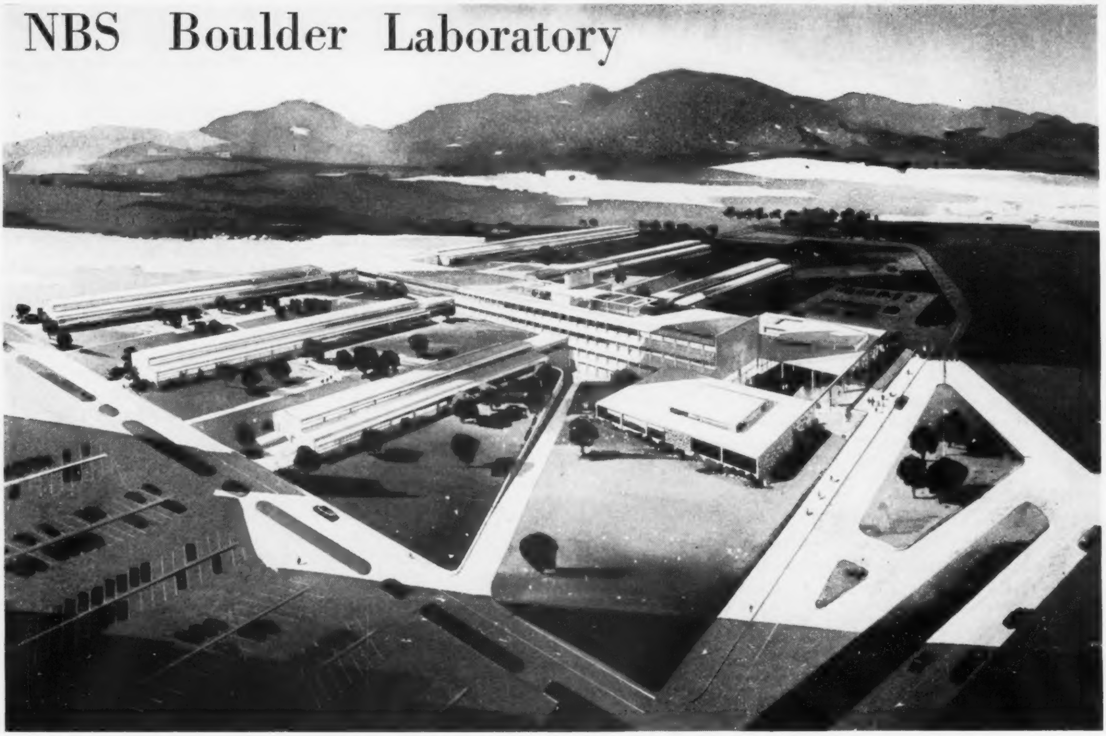
The principles of measurement on which the NBS failure-prediction work has been based are not new, and many better failure-prediction systems undoubtedly can be devised; yet until now very little has been done toward development of practical techniques for semiautomatic checks for detection of incipient failures. The success of the experimental work at NBS suggests that provision for simple failure-prediction routines for the maintenance of important electronic equipment deserves the serious attention of design engineers.

Color in Business, Science, and Industry

THE PRACTICAL uses of color in the purchase, production, and sale of commodities, as well as the basic facts underlying color measurement, are comprehensively covered in a new 401-page book, *Color in Business, Science, and Industry* (John Wiley and Sons, Inc., $6.50) by Dr. Deane B. Judd, in charge of the NBS Colorimetry Unit. Directed toward the physicist, chemist, and technologist in the paint, textile, dyestuffs, plastics, ceramics, and similar industries, the book is based on the thousands of questions on color which Dr. Judd has answered for men in business, research, and industry during his 20 years with the Bureau. Television and motion picture engineers and many others who work with color will find the book useful.

The 17 chapters deal with the eye, aspects of color, color matching, color deficiencies, spectrophotometry, fundamental standards in colorimetry, visual colorimeters, reproduction of pictures in color, colorimetry by difference, color standards, uniform color scales, color languages, gloss, opacity or hiding power, Kubelka-Munk analysis, identification of colorants, and formulation of colorants.

NBS Boulder Laboratory



Architect's drawing of the new NBS radio laboratory at Boulder, Colo. The design of the building features a central spine, with one-story wings extending perpendicularly from it on either side. The structure takes advantage of the sloping terrain that rises from a state highway toward the Flatirons to the west.

CONSTRUCTION has begun on a major laboratory of the Bureau at Boulder, Colo. The new building will house the Bureau's Central Radio Propagation Laboratory on a 210-acre site directly south of the city, near the campus of the University of Colorado. Complete and modern facilities are to be provided for research on the propagation of radio waves and on the expanded utilization of the radio spectrum now being used for FM, television, facsimile, and radar.

The Olson Construction Company of Denver, Colo., has been designated to build the $4,500,000 laboratory from drawings and specifications prepared by Pereira and Luckman and J. E. Stanton, architects and engineers of Los Angeles, Calif., and Robert W. Ditzen, associate architect of Boulder. All construction will be under the direction of the Public Buildings Service of the General Services Administration, Washington, D. C. The building is scheduled for completion in the early part of 1954.

The new NBS laboratory will be constructed of reinforced concrete with stone facing at the main entrance and at other portions of the exterior. The design features a central spine and one-story wings extending outward from either side of it. The front of the building is four stories high, reducing to one story at the rear of the central spine. The structure thus takes advantage of the sloping terrain that rises toward the mountains to the west. A pair of wings join the spine at different floor levels. The central spine is designed so that wings may be added to meet future laboratory requirements.

The NBS Central Radio Propagation Laboratory is engaged in a broad program of basic and applied research in radio physics and associated geophysical phenomena of the upper atmosphere and the troposphere. The program has four aspects: ionospheric research, systems research, measurement standards, and regular propagation services. Investigations are under way dealing with the properties of matter at radio and microwave frequencies and with the development of techniques for the precise measurement of electrical quantities in these regions. One aspect of the basic standards and measurements program is that of obtaining atomic standards of time and frequency. NBS also participates in an advisory capacity on radio subjects for other agencies of the Government such as the Defense and State Departments and the Federal Communications Commission.

More than 50 members of the NBS tropospheric research group are now housed in temporary quarters at Boulder pending completion of the new building. Another group of 20, engaged in studies of long-range propagation techniques, is located at Colorado Springs.

A High-Voltage High-Current Pulse Generator

NEARLY SQUARE-TOPPED pulses at voltages up to 1,200 volts and currents up to several amperes are provided by an electronic pulse generator recently developed at NBS. The pulse frequency is variable in steps of 10 between 10 and 60 pulses per second. Pulse duration, a constant 1 percent of the period at each frequency, ranges from 165 microseconds at 60 cycles to 1,000 microseconds at 10 cycles. W. E. Williams, Jr., of the Bureau's electronic instrumentation laboratory, developed the new device to supply the heavy pulses required in an NBS study of vacuum-tube cathode emission. However, the instrument may have other applications where nearly square-topped pulses are required at high voltages and heavy currents.

Output of the pulse generator is taken between ground and the cathode of a high-power 304TH triode switch tube. The plate voltage of the 304TH is supplied from an adjustable external source of up to 2,000 volts. When the switch tube is receiving no pulse excitation, its grid is biased to cutoff and its cathode is at ground potential. When a pulse drives the 304TH grid positive with respect to cathode (about 130 volts are used), the output voltage rises to a value determined by characteristics of the external power supply and load.

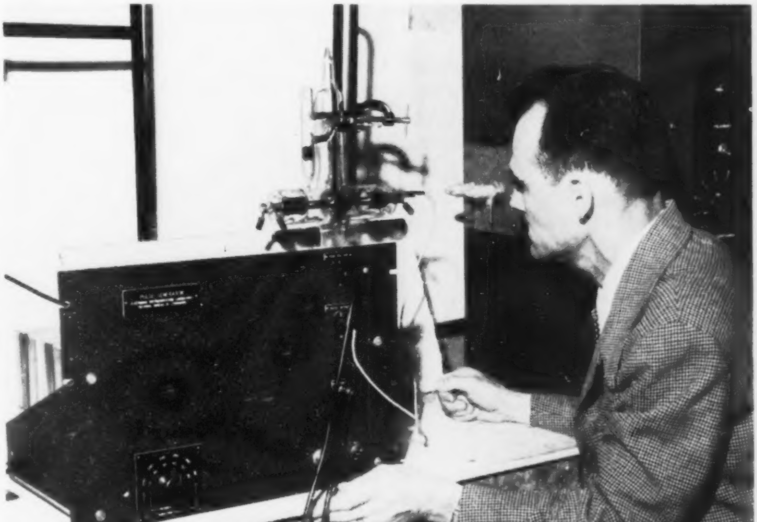
The novelty of the NBS pulse generator lies in the means by which the exciting pulse is supplied to the grid of the 304TH. The most obvious method might seem to be to couple a pulse-forming circuit to the 304TH by means of a pulse transformer. But the transformer would need to be insulated to withstand the high voltages involved, and it would be difficult to construct such a transformer having good response at the low repetition rates as well as good insulation. For this and other considerations, in the adopted circuit a keyed radio-frequency oscillator and rectifier take the place of a pulse transformer.

Pulses are generated initially by a twin-triode 6SN7 vacuum tube in an unbalanced multivibrator circuit. A six-position selector switch gives multivibrator repetition rates of 10, 20, 30, 40, 50, and 60 pulses per second with a constant 1-percent duty cycle. The output of the multivibrator is amplified by a single 6J5 triode and coupled by a 6V6 cathode follower to the screen-grids of a 4.2-megacycle radio-frequency oscillator using two 6L6's in parallel. By this arrangement the oscillator is keyed on for the duration of each pulse. The oscillator output—a 4.2 Mc carrier with 100 percent 10-to-60-cycle near-square-wave modulation—is inductively coupled to a 6X5 rectifier, and the positive-pulse output of the rectifier is applied to the grid of the 304TH output tube. The necessary high-voltage insulation between the two windings of the oscillator coil is readily provided.

In practice, the amplitude of the output pulse decreases slightly in a linear manner at a rate of 0.01 percent per microsecond of pulse duration. This die-away is due primarily to the decrease in plate-supply voltage of the switch tube as the storage capacitor of the power supply discharges. Overshoot of amplitude at the beginning and end of pulses is negligible, an important requirement in the intended application.

For further technical details, see High-power square-pulse generator, *by W. E. Williams, Jr., Electronics* **25,** *No. 10, 144 (October 1952). For a report on the NBS study of vacuum-tube cathode emission, see* Oxide cathode base metal studies, *by R. Forman and G. F. Rouse, J. Research NBS* **46,** *30 (January 1951) RP2171.*

A pulse generator (left foreground) recently developed at NBS is used for supplying current pulses to an experimental twin-diode vacuum tube (rear center). When an external d-c power supply of adequate capacity is used, pulses of nearly square waveform are provided at voltages up to 1,200 volts and currents up to several amperes. By means of a selector switch (lower left), the pulse frequency may be set for 10, 20, 30, 40, 50, or 60 cycles per second. At each frequency, pulse duration is 1 percent of the period.



Stiffness Tester

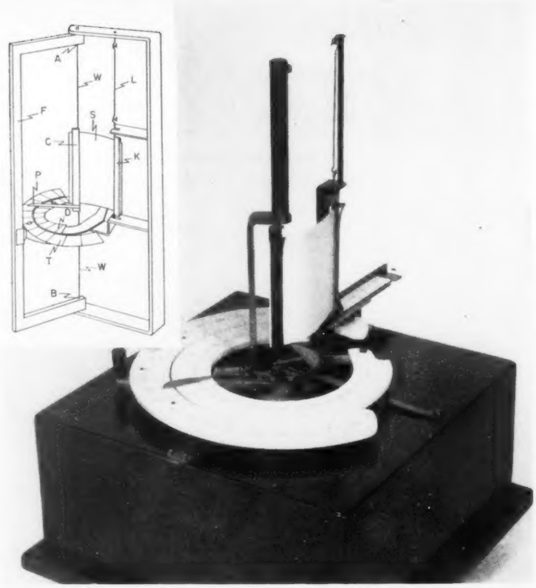
TO MEASURE RAPIDLY and conveniently the stiffness of commercial papers, a sensitive instrument has been developed by F. T. Carson and Vernon Worthington of the National Bureau of Standards. In the new device the specimen is bent through a given angle, and its stiffness is measured by the torque in a wire suspension. By variation in the width and length of the specimen and the angle through which it is bent, and by use of supporting wires of different sizes, instruments of this type could be employed to test papers having a wide range of stiffness. The NBS Stiffness Tester is also expected to prove useful in evaluating the stiffness of thin plastic sheet, textiles, and similar materials.

In many paper products—such as paper towels, currency, and playing cards—stiffness is one of the most important criteria of usefulness. The stiffness of wrappers and containers is a necessary consideration in the use of automatic packaging machinery. Stiffness is also a factor in the "feel" and "rattle" by which the quality of many papers is judged. In the past a number of methods have been proposed for determination of the stiffness of paper and similar materials. Most of these methods, however, evaluated paper stiffness empirically and in a relative manner by measurement of such arbitrary quantities as the force required to bend a strip of given size through a certain angle or to deflect the end of the strip a given amount. The NBS Stiffness Tester was developed to meet the need for a sensitive method which would give consistent values of stiffness independent of specimen dimensions and angle of bending within a usefully wide range.

The NBS device is designed to put a measured twist on the specimen, which is supported in clamps at its two vertical edges. One clamp, through which the torque is applied, is securely attached to the specimen; the other clamp, which applies the reaction, holds the specimen loosely so that it can bend freely and naturally. The first clamp is suspended between two vertical lengths of piano wire, and the outer ends of the wires are fastened to a torque frame. When the torque frame is rotated, the piano wires transmit the applied torque to bend the paper. A pointer attached to the rotating clamp indicates (by its position on a fixed scale) the angle through which the paper is bent and at the same time shows (on a scale attached to the torque frame) the torque applied to the piano wire.

The apparatus owes its sensitivity in considerable degree to a design which eliminates the need of bearings in the torque measuring device. Another advantage of the design, the vertical bending axis, makes the measurement independent of gravity effects.

From the measured values of torque and bending angle and the dimensions of the specimen, the value of stiffness is determined in much the same way as that of a cantilever beam loaded at the free end. However, experimental measurements have shown that the theoretical formula thus obtained must be modified some-



NBS Stiffness Tester developed for rapid determination of stiffness of paper products. Left end of specimen (center) is firmly attached to clamp suspended between two vertical lengths of piano wire, outer ends of which are fastened to torque frame. When torque frame is rotated by means of handle at left, pointer indicates on inner scale the angle through which paper has been bent and outer scale shows the torque applied to wire suspension. *Inset:* Schematic diagram. One end of paper specimen *S* is fastened to clamp *C* while other end is held loosely by similar clamp *K*. Bending torque is applied to clamp *C* through suspension wires *W* by rotation of frame *F*. Applied torque is indicated by position of pointer *P* on scale *T*. At same time, the angle through which clamp *C* has been rotated is shown by position of pointer on scale *D*. Pivots of clamp *K* can move freely in slots in supporting bracket while link *L* supports clamp.

what to take into account the length of the specimen. When this is done, the stiffness (S) is given (for small bending angles) by the equation

$$S=\frac{ML^n}{3b\theta}$$

where M is the bending moment at the torque axis, L is the span or bending length (distance between the axes of the two clamps), b is the width of the specimen, θ is the bending angle, and n is approximately 0.8.

Studies at NBS have shown that this stiffness formula, developed for small bending angles, also gives very consistent results for rather large angles. Thus the NBS Stiffness Tester provides a convenient means for evaluating the stiffness of paper within a bending range corresponding to actual conditions of use.

For further technical details, see The stiffness of paper, *by F. T. Carson and Vernon Worthington, J. Research NBS* **49** (Dec. 1952) RP 2376.

Third Conference on High-Frequency Measurements

PLANS HAVE BEEN COMPLETED for the Third Conference on High-Frequency Measurements, to be held in Washington on January 14 to 16, 1953. As announced in the October issue of the Technical News Bulletin, the conference will be devoted exclusively to the techniques and problems of high-frequency measurements, with particular attention to new developments. It is being sponsored jointly by the American Institute of Electrical Engineers, the Institute of Radio Engineers, and the National Bureau of Standards.

The conference will include four technical sessions, each lasting a half day and consisting of a number of technical papers. Subjects of the technical sessions will be Measurement of Frequency, Wavelength, and Time; Measurement of Power and Attenuation; Measurement of Transmission and Reception; and Measurement of Impedance. The first session will open with introductory remarks by Dr. A. V. Astin, Director of NBS. Two papers to be presented during this session (the first two listed in the program below) deal with recent measurements of the velocity of light and are expected to excite considerable interest.

In addition to the technical sessions, there will be a luncheon meeting on Thursday, January 15, at which Dr. Alan T. Waterman, Director of the National Science Foundation, will speak to the group. Inspection trips through the National Bureau of Standards, the Naval Observatory, the Naval Ordnance Laboratory, and the Naval Research Laboratory will be made on Thursday afternoon, and demonstration lectures will be given Thursday evening.

Registration for the conference will begin at 9:30 a. m., Wednesday, January 15, at the Hotel Statler. The complete program of the technical sessions and demonstration lectures follows.

* * * *

Measurement of Frequency, Wavelength, and Time: Harold Lyons (NBS), presiding.

Precision Measurements of the Velocity of Electromagnetic Waves and the Refractive Indices of Gases at Microwave Frequencies: L. Essen, National Physical Laboratory, England.

Precision Microwave Measurement of Propagation Velocity of Electromagnetic Waves: W. W. Hansen, W. J. Barclay, K. Bol, Stanford University.

The Measurement of Resonant Cavity Characteristics: G. L. Hall and B. Parzen, Federal Telecommunications Laboratories, Nutley, N. J.

Current Microwave Frequency Calibration Procedures at the National Bureau of Standards: Albert E. Wilson, NBS.

New Techniques With Frequency and Time Counters: Alan S. Bagley, Hewlett-Packard Co., Palo Alto, Calif.

Performance and Reliability Considerations of Underground Quartz-Crystal Resonators: Thomas A. Pendleton, NBS.

Electronic Chronograph: W. E. Leavitt, Naval Research Laboratory.

Measurement of Power and Attenuation: E. W. Houghton (Bell Telephone Laboratories), presiding.

Measurement of High Power Breakdown in Transmission Line Components: M. S. Tanenbaum, Sperry Gyroscope Co., New York.

Water Calorimeters in Pressurized Rectangular Wave Guides: Henry H. Grimm, General Electric Co., Syracuse, N. Y.

40–4000 Microwatt Power Meter: R. W. Lange, Bell Telephone Laboratories, Murray Hill, N. J.

A Microwave Double Detection Measuring System With a Single Oscillator: D. H. Ring, Bell Telephone Laboratories, Holmdel, N. J.

A Rectangular-Waveguide Below-Cutoff Attenuator as a Standard of Microwave Attenuation: Robert W. Hedberg, NBS.

A Broad-Band Precision Waveguide Attenuator: B. P. Hand, Hewlett-Packard Co., Palo Alto, Calif.

Measurement of Transmission and Reception: J. W. Kearney (Airborne Instruments Laboratory), presiding.

Frequency Considerations in the Transcontinental Radio Relay System: H. E. Curtis and J. B. Maggio, Bell Telephone Laboratories, Murray Hill, N. J.

A Waveguide Cavity for an Externally Tuned Reflex Oscillator at 9 Kmc: Ned A. Spencer and David Dettinger, Wheeler Laboratories, Great Neck, N. Y.

Recent Developments on a New Type of Wide Range Electronically Tunable Oscillator: S. F. Kaisel, Stanford University.

Millimeter Waves From Harmonic Generator: Charles W. Johnson, The Johns Hopkins University.

A Microwave Correlator: R. M. Page and A. Brodzynsky, Naval Research Laboratory.

A Note on the Stability of Microwave Noise Generators: W. W. Mumford, Bell Telephone Laboratories, Red Bank, N. J.

Signal Generator Terminations for Receiver Measurements: Emerick Toth and Loren S. Bearce, Naval Research Laboratory.

Measurement of Impedance: F. J. Gaffney (Polytechnic Research and Development Co.), presiding.

Swept Wide-Range SWR Indicators for 100 Through 1350 Megacycles: William P. Peyser, Airborne Instruments Laboratory, New York.

Balance Measurements on Balun Transformers: O. M. Woodward, Jr., RCA, Princeton, N. J.

Measurement of Crystal Mixer Dynamic I. F. Admittance: W. T. Doolitle, Jr., and A. Ackerman, Sperry Gyroscope Co., New York.

Design, Performance, and Application of a New Hybrid Junction: M. D. Adcock, Hughes Aircraft Co., Culver City, Calif.

The Design and Construction of a Relatively Inexpensive Long Slotted Line: C. F. Miller, The Johns Hopkins University, Baltimore, Md.

Accurate Comparison of High SWR-Application to the Attenuation Constant of a Waveguide: Georges Deschamps, Federal Telecommunication Laboratories, Inc., Nutley, N. J.

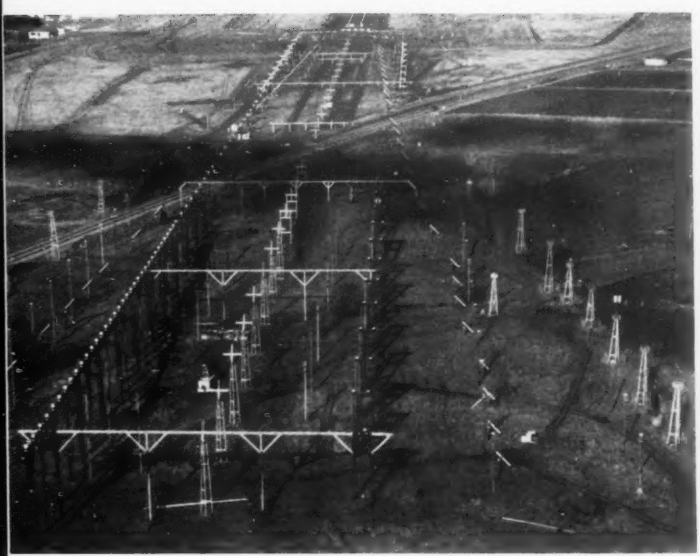
Precision Measurements of Dielectric Constants and Attenuation Constants at Microwave Frequencies: H. M. Altschuler and A. A. Oliner, Microwave Research Institute, Polytechnic Institute of Brooklyn.

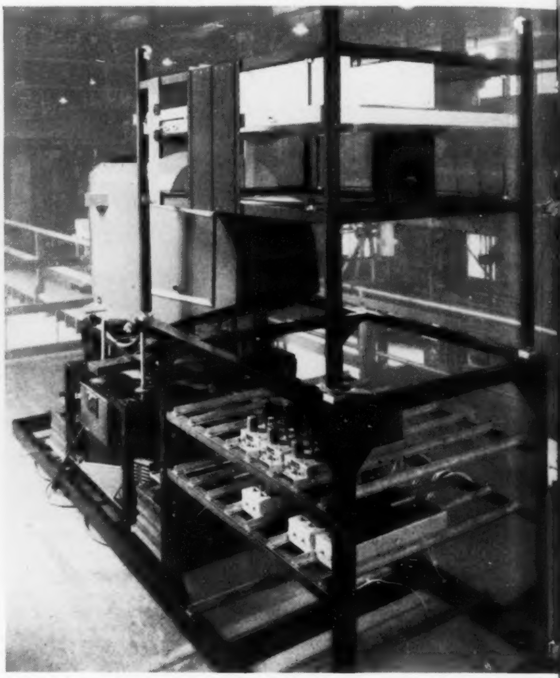
Demonstration Lectures: F. Hamburger, Jr., (AIEE-IRE Committee in High-Frequency Measurements), presiding.

Microwave Propagation on Dielectric Rods and in Ferromagnetic Media: A. G. Fox, Bell Telephone Laboratories, Inc., Holmdel, N. J.

A New Transistor for High Frequency Use: R. L. Wallace, Jr., Bell Telephone Laboratories, Inc., Murray Hill, N. J.

The Kinorama—*a device for evaluating airport*





Above: **Approach-light installation for flight testing. The kinorama is designed to reduce needs for such elaborate installations and costly flight tests. (Photo courtesy Landing Aids Experiment Station, Arcata, California.)** ***Right:*** **View of kinorama showing table assembly which provides forward, crosswise, and vertical movements.**

FOG AT AIRPORTS constitutes a serious hazard to air traffic. Although extensive flight tests have been made to determine which of many proposed approach-light systems is best suited for landing in fog, these tests have thus far failed to bring about agreement on any one system. To supply this need, the National Bureau of Standards, in cooperation with the Navy Bureau of Aeronautics, has developed a device known as the kinorama with which a pilot can evaluate the guidance provided by a system of approach lights without leaving the ground. Perhaps more important in the long range than determining the best approach-light system will be the use of the kinorama in providing pilots with the vital training which can now be acquired only through hazardous experience.

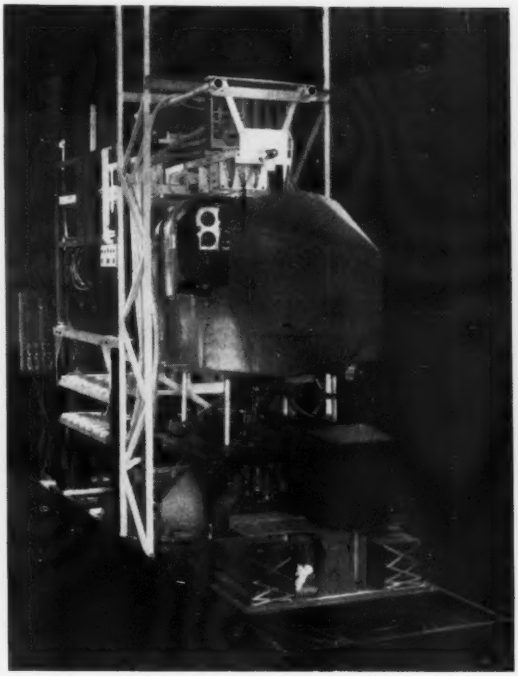
The use of the kinorama makes it possible for the pilot to see an approach-light configuration speeding by him just as he would in flying over it in fog. The course followed in such a simulated flight is determined by the pilot himself, who acts in response to the lights that are visible to him. By recording the paths thus followed, it is possible to obtain objective records reflecting the merits of the light system. While the device is not a substitute for flight testing for the final approval of a system, it is inexpensive, objective, free from hazards, and not dependent upon the occurrence of fog.

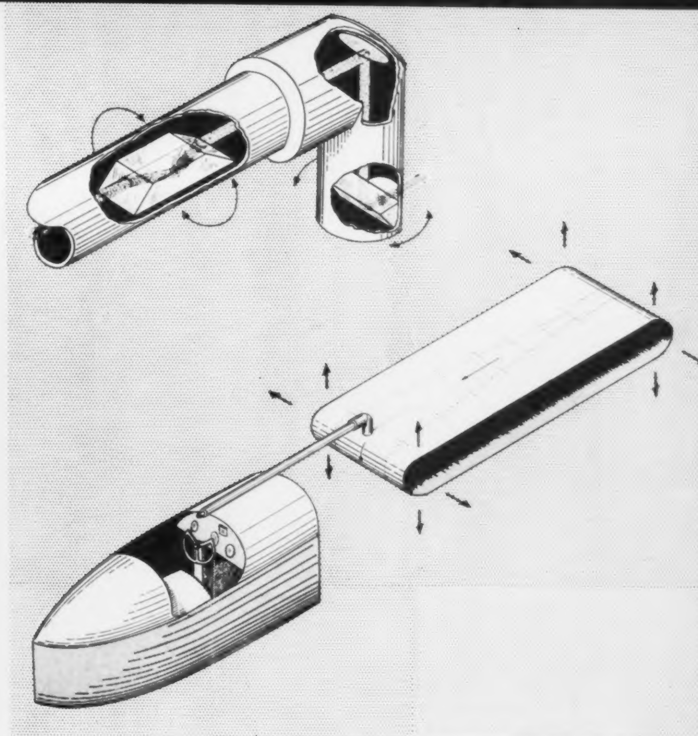
In spite of the excellent electronic equipment which has been developed for guiding pilots in fog, safe landings in bad visibility are not yet a common practice because there remains the problem of making the final contact with the runway. Where so much is at stake, it is desirable, if possible, to make this final contact visually rather than to trust the operation of electronic devices. It is the purpose of the approach lights to furnish an earlier visual contact with the ground.

Many engineers and pilots have attempted to design systems of lights to guide pilots in the critical seventeen seconds between the time the aircraft is near enough to the ground to be within the reach of lights and the pilot's first sight of the runway lighting. Practically all discussion of the merits of these different systems has revolved about stationary aspects of their design, such as the interpretation of geometrical figures, the visual range of the lights, and the possibility of seeing lights in different locations. It is quite evident, however, that approach lights cannot be seen in stationary arrangements by pilots except in the unusual cases of fixed balloons and helicopters.

Two devices which incorporate the natural apparent motions of landing aircraft have been developed for the study of approach-light systems. One of these, called the cyclorama, has been used for some time for demonstrations in England. This device, however, is limited to configurations in a single plane and hence cannot

airport approach lights





Above: **Schematic diagram showing how kinorama produces motions simulating those of airplane by reciprocal movements of endless tape on which approach-light system is represented. Rotations result from movement of telescope prisms (cutaway at top.).** ***Left:*** **The telescope above trainer cockpit is surrounded by electrical equipment for simulating angular movements.**

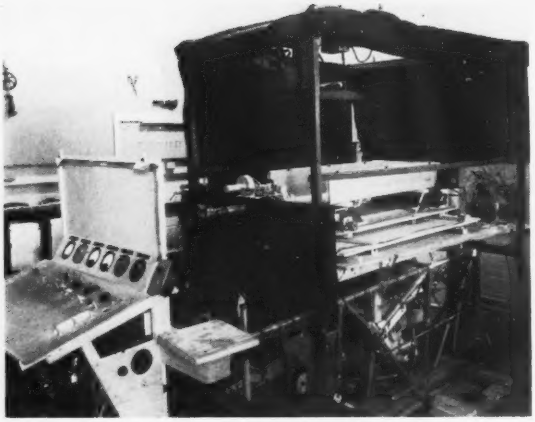
be used for evaluating a three-dimensional arrangement of lights such as the slope-line system. The second device, the NBS kinorama, undertakes a more complete simulation than the cyclorama and includes the three-dimensional aspects of approach-light systems.

Two models of the kinorama have been constructed at the National Bureau of Standards under the direction of F. C. Breckenridge. After the original experimental or laboratory model had demonstrated that it is possible to achieve the desired flight simulations, an improved prototype kinorama was constructed.

The basic principle of the kinorama is to represent an approach lighting system by a small, movable model whose motions are the reciprocal of those which a plane would have in landing over the lighting system. Because the pilot's reaction is the true test of any system being evaluated, the motions of the model must be those which would normally appear to follow the pilot's use of his controls. In the kinorama, the approach lights are represented by fluorescent miniatures of lighting units mounted on an endless tape which moves continuously toward the observer, simulating the plane's forward motion over the approach and runway lights. For lighting systems comprised of units that are all in one plane, it is only necessary to represent the lights by small spots of fluorescent material on the surface of the tape. However, for systems like the slope-line system in which the third dimension is significant the lighting units are represented by miniatures which include the third dimension.

To simulate the lighting system on a sufficiently small scale so that over-all dimensions are kept within practicable limits, the point of observation must be placed very near to the tape in order to make the view correspond to that from points along the approach path. This is accomplished by the use of a telescope with negligible magnification and an objective approximately 0.5 inch in diameter. With a larger objective, it would not be feasible to bring the point of observation sufficiently near the lighting units and only the first stages of an approach could be simulated. With a telescope of sufficient length the pilot can sit in his seat normally and see the lights as if he were coming down among them. The telescope also simplified the problem of simulated banking. It was only necessary to install a dove prism at a suitable location in the telescope and rotate this prism to obtain a realistic simulation of a lighting system as seen from a banking plane.

The laboratory model is built on the fuselage of an airplane with its associated instruments and controls. Hinged plywood platforms, which move relative to one another, provide the apparent motions of flight. In the prototype kinorama, the cockpit, instruments, and con-



Early experimental model of the kinorama. Beyond controller's table at left are the recorders. Pilot sits in front of table and looks through telescope at the configuration which moves toward him in the trough beyond.

trols of a Link trainer take the place of those of the airplane and the plywood platforms are replaced by rectangular frames of aluminum alloy. A true vertical motion has been substituted for the hinged movement. All the angular motions are simulated optically which simplified the mechanical design and made it possible to provide the desired yaw movements with less width. Servomotors control all movements of the kinorama including a recorder which provides a permanent record of each "landing." Special equipment allows automatic presetting of any one of nine initial landing states—that is, the selection of one of nine combinations of three altitudes with three transverse positions, combined with a predetermined yaw, bank and pitch for each state. This flexibility of presetting is sufficient to meet the needs of a wide variety of landing problems.

Evaluation of three different types of visual aids has been undertaken with the kinorama: (1) a comparison of three "over-run" (the "over-run" is a stretch of pavement at one end of a runway which has not been built for regular use but which must be kept free of obstruction for emergencies) lighting systems designed at Wright-Patterson Air Force Base, utilizing different types of lighting units; (2) a comparison of the three approach-light systems proposed for standardization by the International Civil Aviation Organization; and (3) a study of longitudinal and transverse markings for runways. The results of NBS tests with the "over-run" systems and the runway markings have shown satisfactory agreement with corresponding flight tests. The investigation of the approach light systems are as yet incomplete; preliminary results obtained with the laboratory kinorama will be supplemented by tests with the prototype model.

In addition to its usefulness for evaluating lighting systems the kinorama gives promise of being a valuable training device. The use of approach-light systems in good weather does not make a pilot proficient in using them in fog. The irregularity and suddenness with which fogs occur, on the other hand, make it impracticable for a pilot to obtain his training by gradually flying in more and more difficult weather. The kinorama can be used to supplement experience in landings with moderately low ceilings and prepare a pilot for landings with approach lights when the weather has deteriorated and thus obviate the inconvenience of having passengers diverted to alternate landing fields at some distance from their destination.

Decay Constant in Vibrating Systems

IN MECHANICAL and electrical vibrating systems a certain proportion of the oscillatory energy is lost because of the natural damping properties of the device in motion. An electronic instrument recently developed by R. D. Laughlin of the NBS Solid State Physics Laboratory measures the time of decay of these systems—a quantity representative of the lost energy. The instrument has a wide range of application to vibratory systems and can measure decay times from 5 seconds to 5 milliseconds or less with an accuracy of one-half percent.

The NBS instrument was designed specifically to study the internal losses in quartz as a function of temperature and relaxation effects in the alkali halide and other crystals. The need for such experiments arose when crystals were observed to exhibit anomalous losses at elevated temperatures. An X-cut quartz crystal bar, especially prepared and cut at NBS, is heated to high temperatures in an evacuated chamber. The crystal is supported at a vibrational node in a low-loss mounting consisting essentially of a pair of knife edges and a spring clip. A thermocouple in contact with a second bar of quartz provides close temperature control during the experiments. After a signal generator initiates oscillations in the crystal, the output of the freely vibrating crystal is impressed on the decay-constant measuring instrument. The experimental results indicate that the quartz crystal exhibits high-loss characteristics between 200° and 350° C, with the maximum losses occurring at 250° C.

The instrument may be used to study mechanically vibrating systems by means of an electromechanical transducer, such as a quartz plate resonator, attached to the device to convert the energy from mechanical to electrical. Use of auxiliary equipment makes possible further applications for the measurement of the time constant of phosphors, photocells, and other phenomena involving exponential decays.

The time decay measured by the NBS instrument is actually the time increment corresponding to any two selected voltages of an exponential waveform. The transient condition—an exponential decay—may be represented by the equation $V(t)=V_0e^{-\alpha t}$. In the equation, V_0 is the initial amplitude of the decaying

Experimental apparatus used to study internal losses in quartz as function of temperature and relaxation effects in alkali halide and other crystals. Crystal to be studied is supported in low-loss mounting (left and inset) and is set into oscillation by signal generator. A glass tube fits over mounting so that complete arrangement may be evacuated. Vibrations are amplified by unit behind mounting. A unit, incorporating identical voltage comparison circuits (on top of chronoscope), amplifies, differentiates, and shapes decaying voltage into pulses that are used to trigger a precision counter chronoscope (center). Oscilloscope (right) is used to tune the quartz bar to resonance. The inset, an enlarged view of the low-loss mounting, shows knife edges on which quartz bar is supported, quartz bar, spring clip responding to vibrations, and second quartz bar, part of temperature control thermocouple.

voltage, $V(t)$ is the amplitude at any later time t, and α is the damping coefficient associated with the particular circuit or device. The lost energy resulting from the external and internal damping is determined from the value of α. This quantity may be computed from the solution of the above equation for any two times t_1 and t_2 corresponding to known voltages V_1 and V_2. The equation becomes:

$$\alpha = \ln(V_1/V_2)/\Delta t.$$

Thus if it is possible to measure the time Δt. required for the voltage to fall from V_1 to V_2, a determination of the energy lost in a vibrating system is reduced to the division of a fixed number by a varying time.

The NBS method for determining the decay constant of a vibrating system utilizes the principle of voltage-amplitude comparison, in which the time required for the falling exponential waveform to pass from one known voltage to another is measured. A pair of identical circuits amplifies, differentiates, and shapes the decaying voltage into pulses that are used to trigger a precision counter chronoscope. The two circuits are alike except for different reference voltages controlling the time of initiation of the triggering pulses through each circuit. One reference voltage controls the starting pulse, which is passed through the circuit to the chronoscope when the input voltage reaches a selected value. The other reference voltage passes the stopping pulse on to the chronoscope when the input voltage has decayed to the second selected value.

The decaying waveform, which must be essentially d-c in character (containing a minimum of ripple), is impressed on one of the cathodes of a 6AL5 twin diode through the primary windings of a pulse transformer. The anode of the thermionic diode is maintained at a selected potential—for example, 45 volts—supplied by a battery external to the circuit. As long as the cathode potential—decreasing with the decaying waveform—exceeds that of the anode, no conduction can take place through the diode. When the cathode and anode potentials become equal, a small current flows in the diode circuit and a voltage appears across a differentiating circuit in the grid of a 6BA6 high-gain pentode amplifier. This voltage, initially a small pulse, is amplified and its phase is inverted by the pentode. The amplified pulse is impressed upon the cathode of the diode through a capacitor and the secondary of the pulse transformer. The combination of tube- and transformer-phase inversion drives the cathode voltage lower and increases the difference in potential between it and the anode. This action forces heavy conduction in the diode within a very short time after the small initial pulse appears. It is also cumulative and becomes oscillatory in a time determined by the reactances in the regenerative circuit of the 6BA6. Thus, within a very short time after the reference voltage on the anode and the "signal" voltage on the cathode have become equal, a sharply rising oscillatory wave is generated.

The impedance level at the anode of the 6BA6 pentode is high, and any loading of the circuit would adversely influence the speed of response of the complete circuit. Therefore, the circuits following this type of regenerative voltage comparator convert the waveform into a single pulse at an impedance level suitable for triggering a precision counter chronoscope.

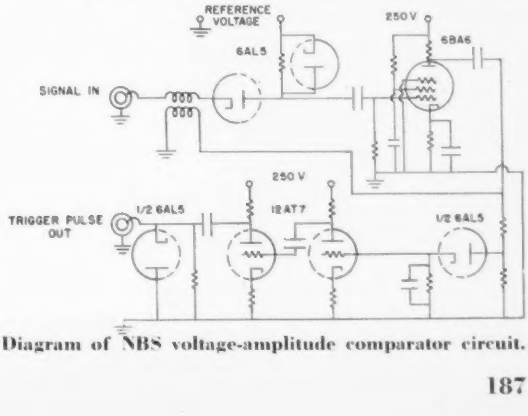


Diagram of NBS voltage-amplitude comparator circuit.

A diode rectifier—one-half of another 6AL5—of short time constant is connected to the anode of the pentode amplifier to convert the input oscillations into a step function containing only a slight ripple. This impulse waveform is amplified in a two-section rise-rate triode amplifier (a 12AT7) that further increases its speed of rise. Another differentiating circuit and an overshoot diode clipper—the second half of a 6AL5—complete the output section.

At the instant the decaying waveform is applied to the circuit described above, it is also impressed on a similar circuit. The second circuit is identical to the first except that the reference voltage on the anode of the comparison diode prevents the circuit from functioning until the input voltage has decayed to a lower value than that in the first circuit, usually 22½ volts. The output pulse of the second circuit then stops the chronoscope. The time difference between 45-volt-triggering and the 22½-volt-stopping pulses is a measure of the vibrating system's damping coefficient.

The accuracy of the NBS decay-constant measurement method was determined by using precision R-C networks, the time constants of which are simply calculated. The error in measuring the time increment was found to be proportional to the length of the increment. Thus, for a 3-second increment the error is 3 percent; and a 0.2 second increment has an error of less than one-half percent.

The principal source of error in the instrument is the inability of the comparator diodes to define the exact moment of voltage equality. The incremental voltage error for a 6AL5 diode used under these conditions if 0.3 volt for a 3-second interval. A random selection of diodes yielded a difference of 4 parts in 1,500 for a time interval of 0.15 second; thus no special selection of diodes is necessary.

Stability over long periods of time is insured by compensating the comparator diodes for thermal drift due to heater aging and temperature variations. The drift voltages are cancelled by use of two diodes in the same envelope. In measurements of decay time in the region of 0.15 second, the compensation maintains the drift to 1 part in 1,500 for periods of several hours.

Seventh Annual Calorimetry Conference

RECENT developments and modifications in precision calorimetric equipment and techniques were discussed at the Seventh Annual Calorimetry Conference, held at NBS on September 19 and 20, 1952. Over 100 calorimetrists attended. The program arranged by Guy Waddington (U. S. Bureau of Mines, Bartlesville, Oklahoma) under the chairmanship of D. R. Stull (Dow Chemical Co.), included a number of individual reports as well as four round-table discussions.

In a brief welcoming address Dr. A. V. Astin, Director of NBS, pointed out the several phases of the Bureau's activities which have involved the development and application of calorimetric techniques. Warren DeSorbo (General Electric Co.) then discussed recent low-temperature calorimetric investigations of some of the elements of Group V and VI of the periodic table. This work has shown that the ordinary Debye theory of specific heats does not give a suitable extrapolation to 0°K for the heat capacities and entropies of monatomic solid elements having one- or two-dimensional crystal lattices. Working with the Van't Hoff equation for freezing point lowering, H. L. Finke (Bureau of Mines) derived an expression relating the change in equilibrium temperature to the fraction melted in cases where solid solutions interfere.

G. S. Parks (Stanford University) described a special sample container which he and K. E. Manchester (Stanford) developed for determination of heats of combustion of volatile organic compounds in an oxygen bomb. E. F. G. Harrington (National Chemical Laboratory, London, England) presented some work on the determination of the heats of combustion of some pyridine bases using a bomb calorimeter. The rotating combustion bomb for use in combustion reactions was discussed by W. N. Hubbard (Bureau of Mines, Bartlesville, Okla.).

J. S. Dugdale (National Research Council, Ottawa, Canada) described some calorimetric measurements by which thermodynamic properties of adsorbed gases may be obtained by use of one-component or "adsorption" thermodynamics. Recent improvements in the flow calorimeter used at NBS for measuring heat capacities of gases were reported by J. F. Masi (NBS). Heat capacity measurements have recently been completed at the Bureau on perfluoroethane, perfluoropropane, and perfluorocyclobutane at a number of different temperatures at several pressures.

A discussion on presentation of calorimetric data in journals was led by G. B. Guthrie, Jr. (Bureau of Mines), and Donald D. Wagman (NBS). Nearly all agreed that publication of "raw" data is desirable.

In a discussion of high-temperature drop and adiabatic calorimetry, led by T. B. Douglas (NBS), problems of shielding, radiation losses, thermocouple errors, and thermal gradients were considered. H. F. Stimson (NBS) stressed the need for an isothermal boundary on an adiabatic calorimeter; he pointed out that the smaller the aneroid calorimeter, the more easily this condition can be realized.

Many new and useful commercial products for use in low-temperature calorimetry were discussed in a session led by Warren DeSorbo (General Electric Co.). Dr. DeSorbo described a new thermocouple of cobalt-gold versus silver-gold with a temperature coefficient about twice that of copper-constantan.

Electronic thermoregulators were treated in a session led by D. C. Ginnings (NBS). F. A. Ransom described a "time-modulated" amplifier used in several electronic regulators at NBS, and E. V. Larson (Minneapolis-Honeywell Regulator Co.) gave details of a thermoregulator used to control an oil bath to a precision of 0.002° at temperatures of 50° to 125° C.

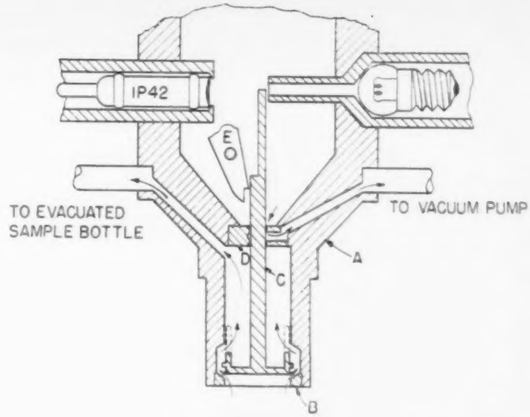
Rapid Gas Sampler

A FAST ACTING mechanical device that takes samples of a rapidly changing gas over extremely short intervals—0.2 millisecond or less—has been recently developed by W. J. Levedahl of the NBS heat and power division. Designed for use in research on the mechanism of engine "knock," the new gas sampling valve is particularly well adapted to studies of the complex changes that take place in the combustion chamber of an automotive engine.

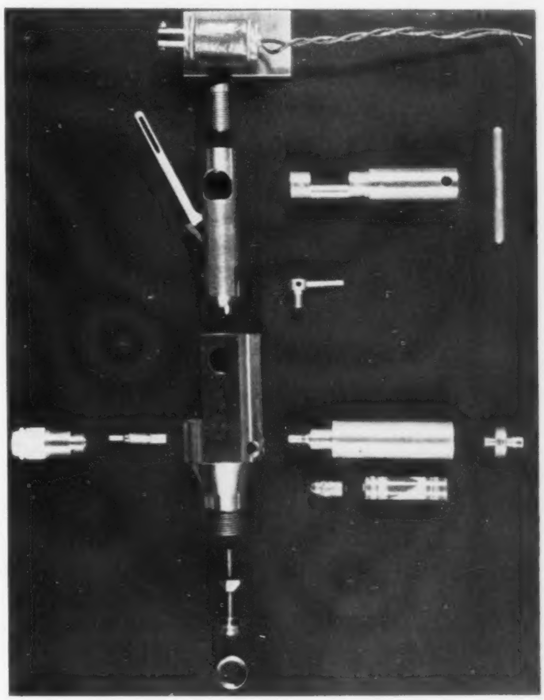
With the cooperation of the Army Ordnance Department the Bureau is now studying the reaction kinetics of knocking combustion in an effort to obtain information that will make possible more efficient utilization of automotive fuels. A single-cylinder test engine in which a wide range of operating conditions may be simulated has been constructed, and the data obtained on the igniting fuel-air mixture are being used to correlate the knocking characteristics of fuels with their chemical structure.

In order to secure significant data on the chemical processes taking place in the cylinder, the investigator must have some knowledge of the proportions of reactants and products present at various times during the combustion cycle. However, multistage combustion reactions of this type are especially difficult to study because of the very short duration of each stage (between 0.1 and 1 millisecond), the extreme complexity of the reaction mechanism, and the fact that many of the important particles are free radicals whose half-lives are probably 1 millisecond or less. Thus, if the combustion gases are to be sampled, the samples must be taken over extremely short intervals during a single cycle of operation, and the reaction must be frozen almost completely upon removal of the sample from the combustion chamber. At the same time, the samples must be large enough for a complete analysis in a mass spectrometer, and the length of the sampling interval must be accurately known to permit correlation between the gas composition and the other measured quantities. The NBS gas sampler was developed to meet these requirements.

Essentially the sampling valve consists of a flanged piston which moves in an evacuated chamber. The valve chamber is connected at its upper end to a vacuum pump and an evacuated sample container. Its lower end first widens abruptly and then narrows to form a connection with the combustion chamber. Initially the operator closes the valve manually by pressing the piston down so that its lapped flange seats against the edge of the combustion chamber opening. The short length of piston below the flange extends into the opening, completely sealing it off. The valve is held in this position by a trigger device outside the valve chamber. When the trigger is released by a solenoid mechanism, the pressure of the gases in the combustion chamber accelerates the piston upward through the



Above: **Cross-sectional diagram of rapid-action gas sampler. Body *A* of valve is designed to fit $\frac{7}{8}$-inch spark plug hole. In initial closed position, lapped flange of piston *C* is pressed against lower seat *B* of valve by trigger *E*. Groove in bushing *D* is connected directly to vacuum pump so that any atmospheric leakage between piston shaft and guide will not reach sample bulb. *Below:* Exploded view of sampler. Solenoid at top activates trigger (upper left), releasing valve piston. At upper right is manually operated cam device for closing valve. Set screw (right center) locks cam in position. At lower left are parts of photocell; at lower right are flashlight bulb, battery, and holder. Just below valve chamber (lower center) is piston and lower valve seat.**



valve chamber so that it is moving with appreciable velocity by the time its lower edge passes out of the combustion chamber opening. At this time the cylinder gases begin passing around the piston head and continue to do so until the upper edge of the head passes into the smaller-diameter upper portion of the valve chamber. The flange then causes the piston head to seat at this point, completely closing the valve. If bouncing occurs, it will not cause the valve to reopen.

While the piston is rising, the connection to the vacuum pump is kept closed so that all the combustion gases pass into the sample container. Meanwhile, an extension of the piston shaft progressively cuts off the passage of light from a flashlight bulb to a small 1P42 photoelectric cell. Thus, when the output of the phototube is differentiated, a square wave indicating the time of opening and closing of the valve is obtained on the screen of an oscilloscope used to present pressure changes within the cylinder. Any bouncing or reopening that might occur would also be made visually evident in this way.

In general, the duration of valve opening and the total mass of gas admitted are dependent upon cylinder pressure at the time of the valve opening. Thus, for example, if the pressure is 80 lb/in^2, about 1 milliliter of gas (reduced to standard temperature and pressure) will flow in 0.2 millisecond, while at 500 lb/in^2 the flow is approximately 4 milliliters in 0.1 millisecond. This decrease in the duration of sampling with increasing pressure is advantageous inasmuch as the reactions studied occur more rapidly at the higher densities.

For further technical details, see Instrumentation for detonation research, *by William J. Levedahl, Inst. Soc. Am. Paper No. 52-27-3. See also* An apparatus for studying autoignition of engine fuels: results with normal heptane and normal hexane, *by William J. Levedahl and Frank L. Howard, J. Research NBS* ***46,*** *301 (1951) RP2200.*

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **49**, number 5, November 1952 (RP2365 to RP2371, incl.). Annual subscription, $5.50.

Technical News Bulletin, volume **36**, number 11, November 1952, 10 cents. Annual subscription, $1.00.

CRPL-D99. Basic Radio Propagation Predictions for February 1953. Three months in advance. Issued November 1952. 10 cents. Annual subscription, $1.00.

Research Papers

RP2358. Mass spectra of the tetramethyl compounds of carbon, silicon, germanium, tin, and lead. Vernon H. Dibeler. 10 cents.

RP2359. Determination of planeness and bending of optical flats. Walter B. Emerson. 10 cents.

RP2360. Index of refraction of magnesium oxide. Robert E. Stephens and Irving H. Malitson. 5 cents.

RP2361. Refractivity of potassium bromide for visible wavelengths. Robert J. Spindler and William S. Rodney. 10 cents.

RP2362. On approximate solutions of systems of linear inequalities. Alan J. Hoffman. 5 cents.

RP2363. Deuterium and hydrogen electrode characteristics of lithia-silica glasses. Donald Hubbard and Given W. Cleek. 10 cents.

RP2364. Calorimetric properties of polytetrafluoroethylene (Teflon) from 0° to 365°. George T. Furukawa, Robert E. McCoskey, and Gerard J. King. 10 cents.

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C506. Automotive antifreezes. (Supersedes Circular 474.) 15 cents.

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